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PROBABILISTIC ANALYSIS OF BELT TENSION

BY

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ABSTRACT

The primary objective of this project is to study the probability distribution of the load on a shaft which is transmitted by a V-belt. Expressing the load using a probabilistic model will aid the computation of shaft reliability.

This project consists of a theoretical analysis and an experimental validation. Theoretical analysis is used to derive the relation between the tension, pressing force and belt modulus. An equation is presented in this paper as the base of the experiment to find the belt tension.

In the experiment, an INSTRON universal tension machine, which has been modified with fixtures to hold a V-belt, is the primary instrument used to measure the tension of a V-belt. The tension tester applies a pressing force at the center of the belt span. The belt modulus factor is then calculated from the results of the experiment. The probability distribution of tension is presented by a Weibull function.

CHAPTER 1

INTRODUCTION

V-belts are widely used in industry to transmit power from a driving sheave to a driven sheave. The tension of the belt will affect the efficiency of the power transmitted and the life time of the belt. Moreover, the load on a shaft is influenced by the tension of the belt and is the primary factor controling shaft fracture. In this experiment, a set of belt cross section moduli will be found, and the load and monent will be computed by a probabilistic model.

The initial work in this project was to find the belt cross section modulus. A INSTRON universal tension machine was applied as the measurement instrument for tension and extension. A fixture was designed to hold and extend the V-belt on an INSTRON machine. Pressing the tension tester at the center of the span, V-belt variations of tension and displacement were measured and the belt cross section modulus was determined.

A group value of E was then obtained for each belt which was based on a series of different pressing forces. Using a probabilistic analysis, the distribution of shaft load can be used to calculate the resulting bending moment on the shaft.

CHAPTER 2

MEASUREMENT OF BELT CROSS SECTION MODULUS

A. Mathematical Expression :

The most common method to determine a static belt tension is to apply a known force at the center of span and measure the displacement of deflection. The configuration of tension test is shown in Fig. 1.

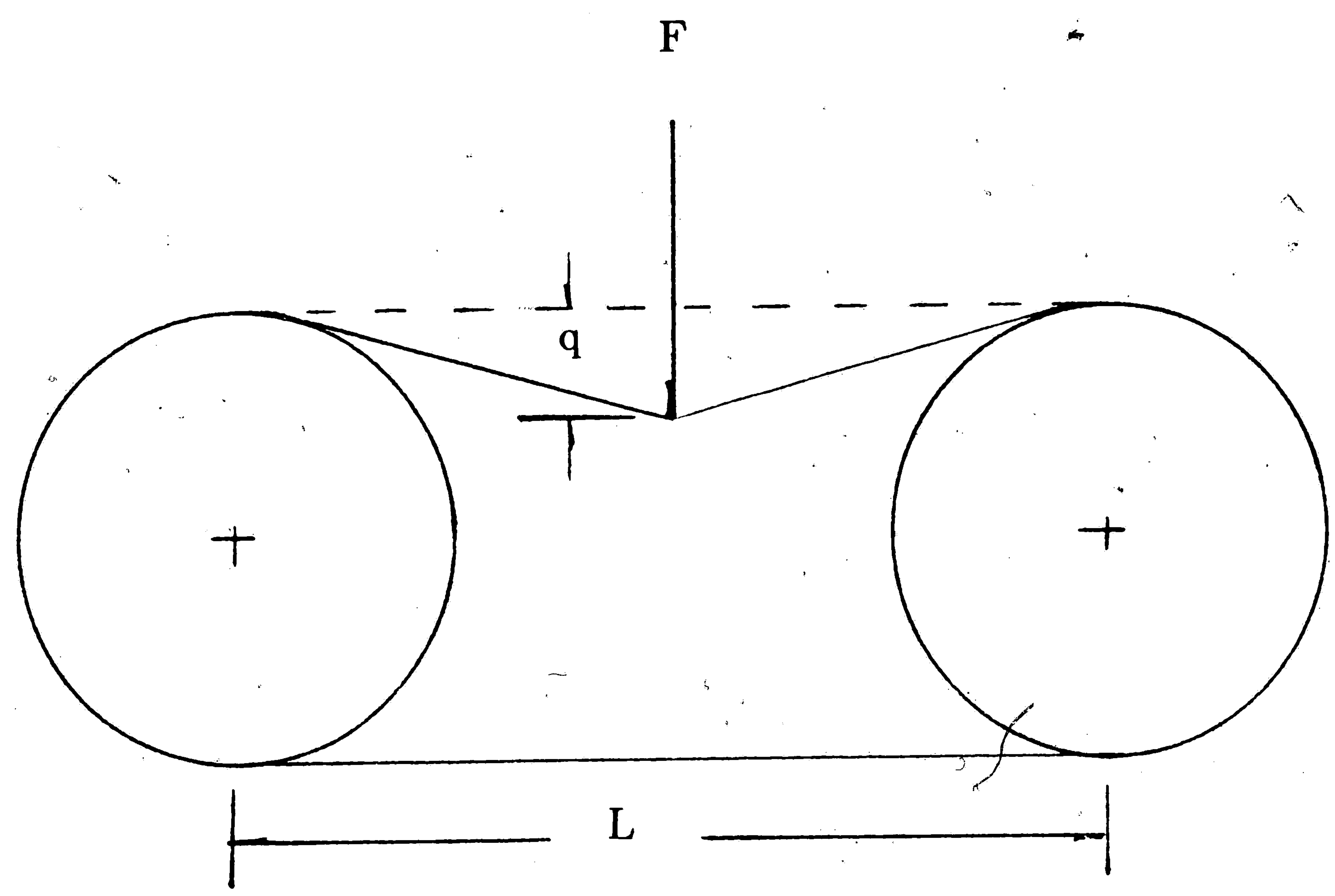


Fig. 1. Configuration of Tension Test

Pressing a force at the center of the span, the deflected tension Tq is equal to the sum of initial strand tension Ts and increment ΔT.

$$Tq = Ts + \Delta T \qquad \text{------------------------------} (1)$$

Since

$$\sin \alpha = \frac{q}{\sqrt{(c/2)^2 + q^2}}$$

and

$$\frac{F}{2} = Tq \cdot \sin \alpha$$

Thus the deflected tension Tq in terms of F is

$$Tq = \frac{F}{2} \left(\frac{\sqrt{q^2 + (c/2)^2}}{q} \right) \text{------------------------------------} (2)$$

Since

$$\Delta T = \frac{\Delta L}{L} E \text{--} (3)$$

$$\Delta L = 2 \left(\sqrt{q + (c/2)} - \frac{c}{2} \right) \text{------------------------------------} (4)$$

Thus

$$\Delta T = \frac{2E}{L} \left(\sqrt{q^2 + (c/2)^2} - \frac{c}{2} \right) \text{------------------------------} (5)$$

Since the ratio of deflection to span or to center distance is small, the value of q^2 in equation (2) becomes a negligible factor and equation (4) may be written :

$$Tq = \frac{F}{2} \cdot \frac{(c/2)}{q} = \frac{FC}{4q} \text{---} (6)$$

In addition, if the ratio q/c is small, equation (5) may be approximated as follows:

$$\Delta T = \frac{2EC}{L} \left(\frac{1}{C/L} \right)^2 = \frac{2Eq^2}{CL} \text{-------------------------------} (7)$$

But

$$Tq = Ts + \Delta T$$

thus the initial strand tension is

$$Ts = \frac{FC}{4q} - \frac{2Eq^2}{CL} \text{--} (8)$$

Equation (8) is used in this paper to determine the value of E in any known value set of pressing force, tension and deflection displacement.

B. Experiment Preparation :

Experiment Instrumentation :

The purpose of this experiment is to find the belt cross section modulus E. From equation (8), the pressing force (F), strand tension (Ts), length of span (C), length of belt (L) and deflection (q) should be known to find the value of E. The following instruments and tools are used in this experiment to measure or read values which are needed to find E.

* INSTRON Universal Testing Instrument

INSTRON is the primary instrument used in the tension test. The tension is obtained by moving a crosshead. The moving speed of the crosshead is controlable. The load and extension are indicated on a readout. The V-belt fixture can be installed on the instrument. The specification of INSTRON is shown in Appendix 1.

* V-belt

A 4L FHP V-belt was selected as the sample to be tested. This is a Fractional HorsePower V-belt commonly used in light duty power transmition. It's characteristics and dimensions are suitable for testing on an INSTRON. The 10 4L FHP V-belts preparation, and specifications are shown in Appendix 2.

* Sheave

In order to fit the dimension of INSTRON and belt, two one-grooved bored-to-size FHP sheaves were selected to hold the V-belt and was connected with INSTRON. The specification of the sheaves is shown in Appendix 3.

* Tension Tester

The tension tester shown in Fig. 2 is a common tool used in tension test for the belt installation. It is a spring gage used to measure the pressing force, the pressing force can be read from the scale on the tester.

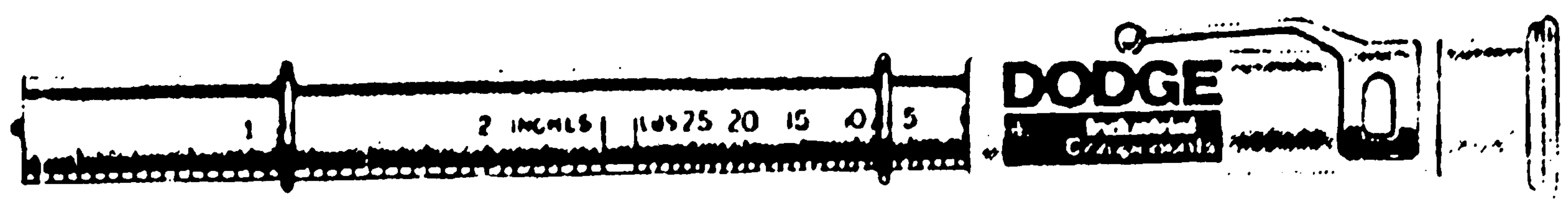


Fig. 2 Tension Tester

* Caliper

The caliper is used to measure the distance between center of the sheaves to determine the length of span and the total length of the V-belt. The measuring range of the caliper is larger than 10 in. and is accurate to within .001 inch..

* Dial Gage

The dial Gage used in this experiment is an accurate gage with a range of 1 inch and is accurate to within .001 in. It is used to measure the deflection of the V-belt where the tension tester is applied.

Fixture Design

The function of the fixture is to fix the sheaves and V-belt to the adapter on the INSTRON. The fixture consisted of two U-shaped frames with a welded head and three 1/2 inch holes. The cylinderical head was designed to fit with the adapter on the INSTRON and fixed by a pin which was inserted through the hole. Two holes were drilled on the legs of the frame to fix the sheave by a pin. Refer to Appendix 4 for further details on the fixture design.

Tolerances and surface roughness were controled to enable the sheaves to rotate freely. The pins and holes were lubricated by grease before assembly to reduce the friction during sheave rotation, Thus the tensions on both sides of the belt were approximately equal.

The U-shaped frame was formed by milling a low carbon steel bar then welding a cylindrical head in place. In order to ensure integrity, the welding strength was calculated and shown in Applendix 5.

Instrument Preparation

* Testing Range Selection

100 lb. was estimated as the maximum durable tension of a FPH V-belt, thus a 1000 lb. tranducer was used on the INSTRON and the scale was adjusted to 200 pounds. All other switch settings are recorded in Table 1.

TABLE 1

INSTRON Range and Switch Setting

Load Transducer Type	: 1000 lb	Eng / Met Switch	: Eng.
Ranger Switch Setting	: 2	Speed Selector Position	: 2
Full Scale Load	: 200 lb	Crosshead Speed	: 1.0 in/min
Decimal Point Setting at Full Scale Load	: 199.9		

* Calibration

In order to reduce error, the instrument was calibrated before operation. The procedure of calibration is shown in Appendix 6. After all components were installed, the INSTRON was calibrated again to get the net load resulting only from the extension of the belt.

C. Experiment

* Wide Range Tension Test

The purpose of this experiment was to find the value of belt cross section modulus E. The crosshead of the INSTRON was moved .1 in/min to extend the V-belt which was placed on the sheaves. The belt was rotated around the sheaves at least two revolutions to properly seat it in the sheave grooves and to equally divide the total tension between the two strands of the belt. The belt was then loaded to 35 lbs as recorded by the INSTRON. The length of the belt (L) and the span (C) were then determined by measuring the distance between the two sheaves.

The belt tension was changed by pressing the tension tester at the mid-point of the belt. Deflection was measured by placing a dial gage on the back of the deflected belt. The load before applying the tension tester was recorded as L_0. The tension tester was then placed at the center of the span and used to apply a force to deflect the belt. When the pre-determined deflection (q) was reached, the load (L_q) and force (F) which was read from the scale on the tension tester were recorded.

The deflection q was divided into 19 steps from .1 to .64 inch. The procedure was then repeated at different deflections and the value of L_0, L_q, F and q were recorded. This data is shown in Table 2.

* Narrow Range Tension Test

In order to simplify the formula, q= c/64 is used frequently in the industry to test belt tension. Above this deflection, a larger error will occur due to the elasticity of the belt. A narrow range was selected from q = c/64 to .22 and divided into 8 steps. The previous procedure was repeated and the result are shown in Table 3.

* Extension and Tension Test

In order to test the relation between tension and extension of a belt, the crosshead was moved slowly. The distance between the center of the sheaves was recorded at 10 pounds increments between 10 and 190 pounds. The data is shown in Table 4.

* Belt Relaxation Test

The purpose of this test was to find the variation of tension from an extended belt. The crosshead was moved slowly until the load was 70 lb then the switch was turned off. The decrease in belt tension was recorded over time. The data is shown in Table 5.

* Lateral Force Effect Test

In order to examine the effect of a lateral force on the tension, All fixtures, sheaves and belts were removed from the INSTRON and replaced by a bolt which was screwed into the hole on the crosshead. The configuration is shown in Fig. 3.

A perpendicular force was then applied at the bolt head in 5 pounds increments between 10 and 30 pounds . The force and the resulting load of the INSTRON were recorded and are shown in Table 6.

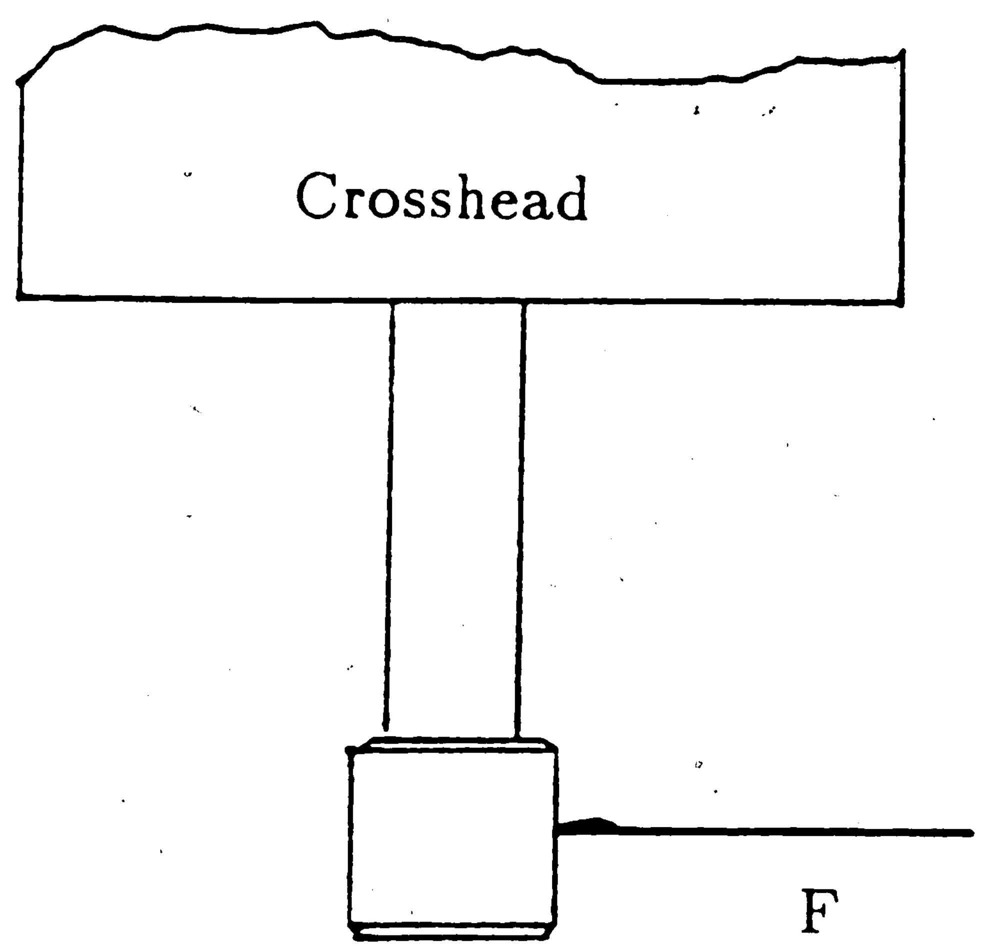


Fig. 3 Configuration of Lateral Force Effect Test

D. Result and Interpretation

1. Wide Range Tension Test

Substituting the values of L_0, L_q, q, L and C, which were obtained from Wide Range Tension Test, into equation 8, a group value of E which varies with different deflections q can be obtained. There were 10 belts to be tested, so 10 groups of data and E were obtained .

From equation 8, we got

$$E_1 = \left(\frac{FC}{4q} - Ts \right) \frac{CL}{2q^2} \qquad \text{-------------------------------------(9)}$$

In equation 9, the values of span (C), deflection (q) and length of belt (L) were read or measured accurately. However, the values of F and T_s were quite rough.

The value of F was measured by the tension tester which was not sensitive or accurate. When the force was less than 5 lb, it was hard to read the right reading of force from the scale. Due to the elasticity of the belt, the tension of the belt varies with time. The initial load L_0 decreased with the increasing of pressing force F.

These two factors resulted in the error of E, especially when F is small. The values of E vary from the highest E = 80979 (# 10) to the lowest E = -970 (#1).

In order to correct the error, we reform the equation 2 into equation 10.

$$F = 2\ T_q \left(\frac{q}{\sqrt{q^2 + (c/2)^2}} \right) \qquad \text{-----------------------------------} (10)$$

We assume that $T_q = \frac{1}{2} L_q$, L_q can be read from the INSTRON when a force F is applied to the belt. F can be obtained from equation 10, these values of F are much more accurate than that which were read from tension tester.

Substituting F and other data which were obtained from this experiment into equation 9, a new belt cross section modulus E_2 was obtained and is shown in Table 7.

2. Narrow Range Tension Test

We assume that $T_q = \frac{1}{2} L_q$ and substitute it into equation 2 to find E. This assumption is reasonable when F is small. For larger F, the friction force between the belt and sheave cause the tension on the two sides of the belt to be unequal. The tension on the side of the belt which is under force F is larger than that of the other side without F. When F is small, the difference in tensions betweenthe two sides is very small, so $T_q \approx \frac{1}{2}L_q$. The elasiticity of the belt which affects the tension of the belt can be neglected, and the derived F is much more accurate than that measured from tension tester, thus, the value of E_2 is more reasonable than the value of E_1.

3. Extension and Tension Test

A curve was plotted using the data obtained in the extension and tension test. The distance between the center of the pins was plotted on the X axis and the load read from INSTRON was plotted on the Y axis. An approximately straight line shown in Graph 1 was obtained. This graph shows that the tension of a belt is directly proporional to the extended distance of the belt.

4. Belt Relaxation Test

Due to the elasticity, the tension of a constantly extended belt will vary with time. Ploting the data which was obtained in the belt relaxation test, a hyperbolic curve was plotted in Graph. 2.

5. Lateral Force Effect Test

From this experiment, we showed that applying a lateral force affects the longitudinal load. In a tension test, a lateral force was shown to create a compression force which reduced the tension force. In the narrow range tension test, a lower force ($F < 4$ lb) was applied to reduce the error, and we obtained a correction factor of -.1 6 by extrapolation. (shown in Graph. 3)

The correction factor which we obtained in Graph. 3 is small when compared with the load. Thus, we can neglect the correction of lateral force to longitudinal load in our experiment.

CHAPTER 3

PROBABILISTIC ANALYSIS OF TENSION AND LOAD

Comparing the wide range tension test and narrow range tension test, the latter is more accurate than the former. Thus, the data which we obtained in the narrow range tension test will be used in the probabilistic analysis.

The distributions of each group value of E_2 in the narrow range tension test are almost same. Therefore, only 3 in 10 groups of data will be treated in the following analysis. Substituting the values of E_2, F, L and q of #10, #9 and #8 into equation 8.

$$T_s = \frac{FC}{4q} - \frac{2Eq^2}{CL} \qquad \text{--} (8)$$

Three groups of T_s can be obtained shown in Table 8.

Graphical estimation can be used with the Weibull distribution to estimate the Weibull parameters. The natural logarithm is taken twice to the cumulative distribution function for the Weibull yields

$$\ln\left(\ln \frac{1}{1- F(t)}\right) = \beta \ln t - \beta \ln \theta \qquad \text{------------------------} (9)$$

Which is clearly of the form $Y = \ln\left(\ln \frac{1}{1- F(t)}\right)$ and $X = \ln t$, "β" is the slope of the straight line and "$\beta \ln \theta$" is the constant.

$F(T_s)$ is the median rank and we can find it from a rank table and substitute in the form

$$\ln\left(\ln \frac{1}{1- F(t)}\right)$$

as the scale on the Y axis. This data is shown in Table 9.

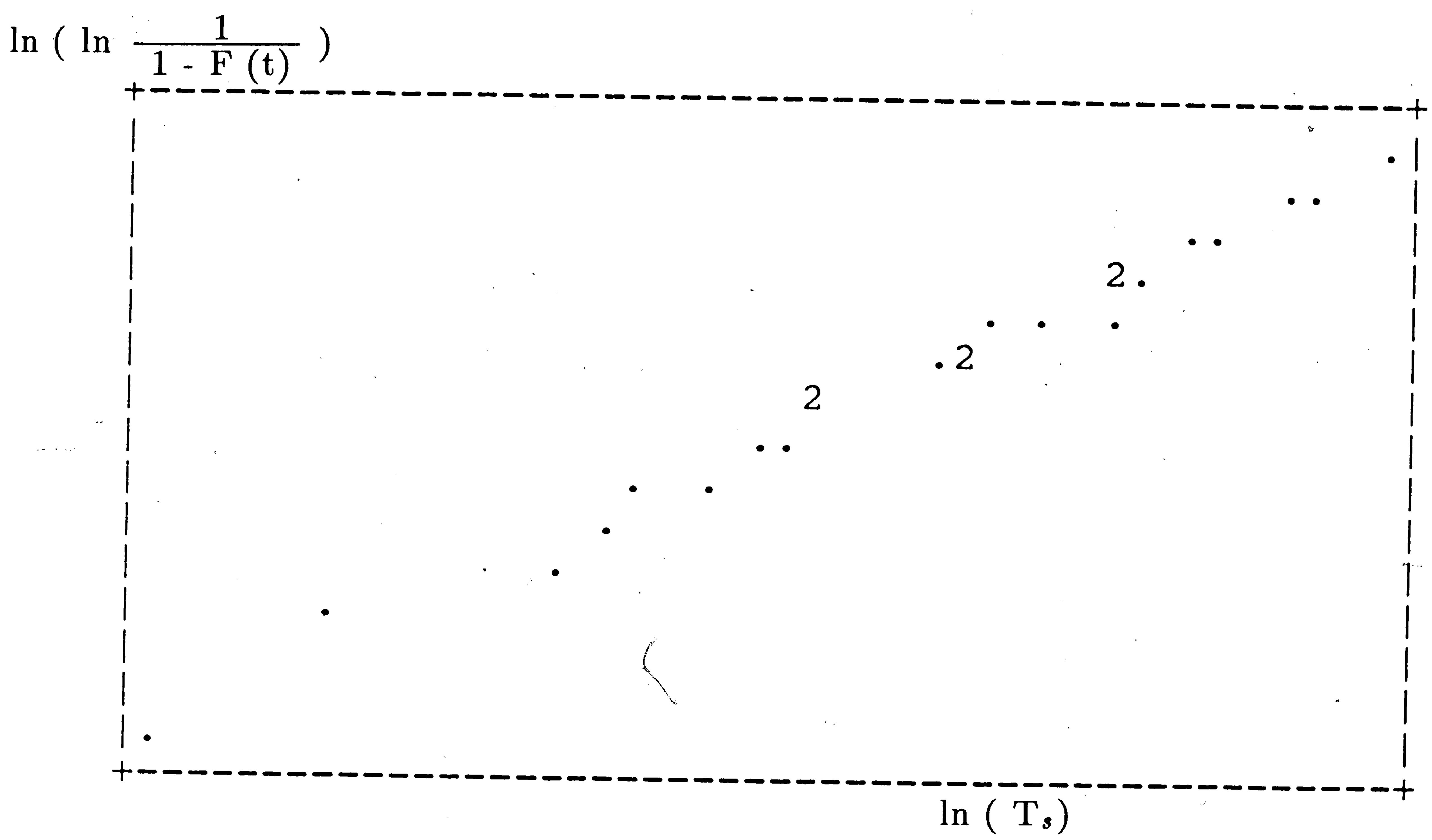
The software package EXPLORE, which uses a least-square fitting method was used to find the approximate equation of the data in Table 9. The binomial coefficients were estimate to be :

$$Y = 36.503143\ X - 102.5717$$

thus $\beta = 36.503143$ which is the slope of the fitted straight line, and

$$\beta \ln \theta = 102.5717$$

The scale parameter, $\theta = 16.609$. All related data are shown in Appendix 7.



Graph. 4 Plotting on Weibull paper

The mean of the Weibull distribution is

$$\mu = \theta\ \Gamma\ (\ 1 + \frac{1}{\beta}\ ) \qquad \text{------------------} (10)$$

and the variance is

$$\sigma^2 = \theta^2\ [\ \Gamma\ (\ 1 + \frac{2}{\beta}\ ) - \Gamma^2\ (\ 1 + \frac{1}{\beta})\ ] \qquad \text{------------------} (11)$$

Hence the mean and the variance of tension are

$$E(T_s) = 16.355$$

$$V(T_s) = .9285$$

F_1 and F_2 are the individual belt tensions on each side of the sheaves. When the sheaves are static, there is no power transmitted by the belt, F_1 and F_2 are equal and both presented as strand tension T_s.

When the driver transmits power, the tension F_1 increases and F_2 decrease due to the friction between the belt and groove of the sheaves. As a result, F_1 is commonly called the tight side tension and F_2 is called the slack side tension.

ΔT represents the difference of F_1 and F_2 and is caused by the friction between the sheaves and the belt.

$$\Delta T = \frac{HP(33000)}{V} \qquad (12)$$

Where V is the speed of belt,

$$V = \frac{(rpm)\,(d)}{3.82} \qquad (13)$$

The specification of the driving components are as follows :

The number of V-belts : 4

Horsepower transmitted by 1 V-belt : 0.2 HP.

Diameter of driver : 3.5 in.

Revolution of driver : 600 rpm.

Hence $V = 549.74$ fpm and $\Delta T = 12.00567$ lb. Since

Tension on tight side $\quad T_1 = T_s + \frac{\Delta T}{2}$

Tension on slack side $\quad T_2 = T_s - \frac{\Delta T}{2}$

T_s is a random variable with Expectation $E(T_s)$ and Variance $V(T_s)$, and ΔT is a constant, then the expectation of tension on tight and slack sides are

$$E(T_1) = E(T_s) + \frac{\Delta T}{2} = 22.358$$

$$E(T_2) = E(T_s) - \frac{\Delta T}{2} = 10.352$$

and variance

$$V(T_1) = V(T_2) = V(T_s) = .9285$$

These equations statistically describe the tension in a rotating belt.

CHAPTER 4

BENDING MOMENT ON THE SHAFT

Designing a driving system, the load on a shaft is resulted from the tension of the belt, weight of the sheaves and the weight distribution of the shaft. We will now consider the normal case of a V-belt transmitting mechanism in which two sheaves with different diameter incline to an angle. The configuation of the transmitting mechanism is shown in Fig. 4.

The angular deviation from the 180° angle of contact due to the different diameters of the two sheaves can be obtained :

$$\theta = \sin^{-1} \frac{\frac{D_0}{2} - \frac{d_0}{2}}{C} \qquad \text{---} (14)$$

C is the center distance between sheaves and

$$C = \frac{b + \sqrt{b^2 - 32 (D_0 - d_0)^2}}{16} \qquad \text{------------------------------} (15)$$

where $b = 4L\text{-}6.28 (D_0 + d_0)$

L = belt effective length

thus $\theta = 13.3937^o$

and $\alpha_1 = \theta = \alpha_2$

$\alpha = 2\theta = 26.7874^o$The resultant load R is

$$R = \sqrt{T_1^{\,2} + T_2^{\,2} + 2T_1 T_2 \cos\alpha} \qquad \text{------------------------------} (16)$$

For a function of random variables x, the expectation and variance are

$$E (Y) = E [f(x)] \approx f (\mu) \qquad \text{--} (17)$$

$$V (Y) \approx [f' (\mu)]^2 V (x) \qquad \text{---} (18)$$

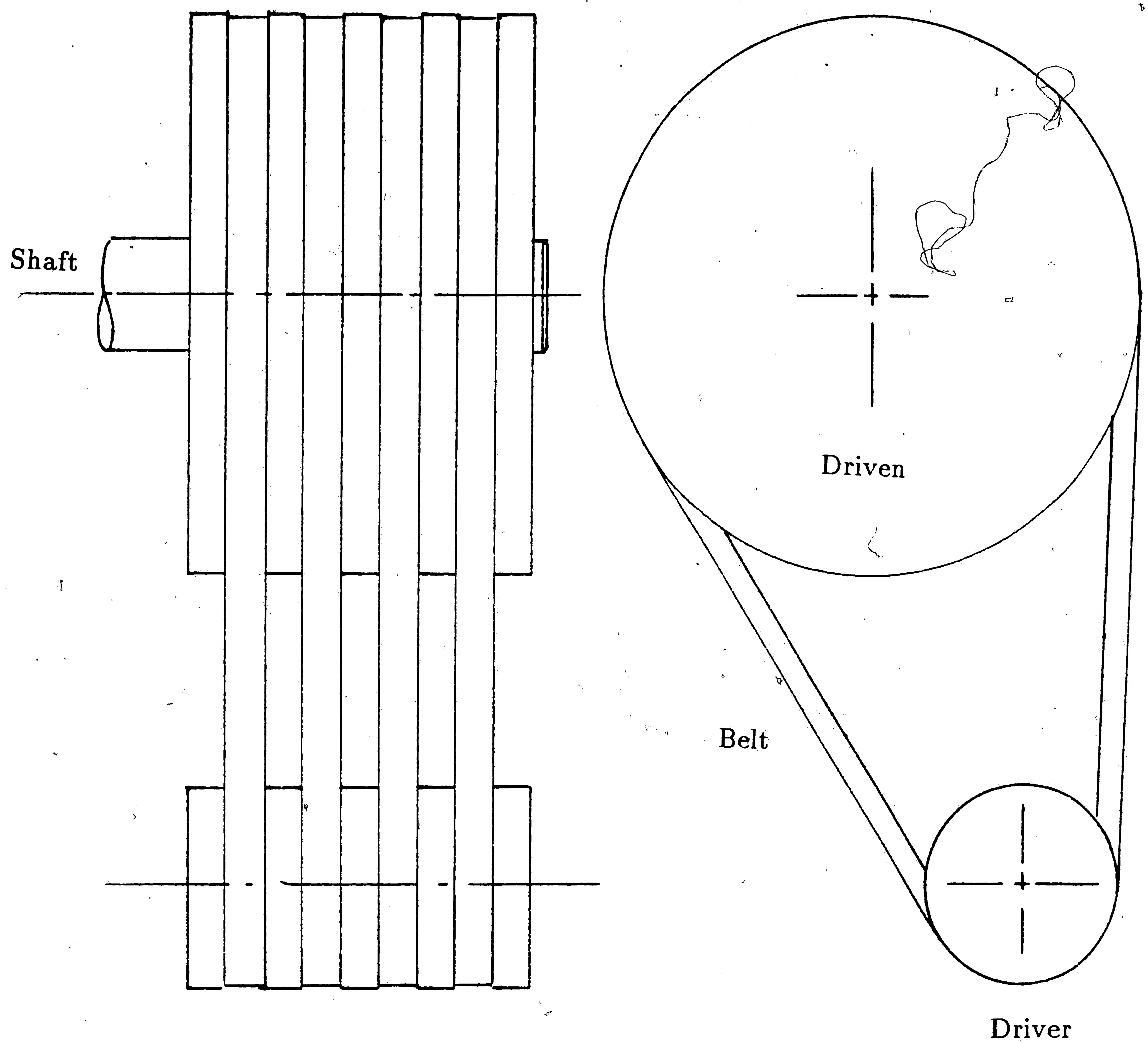


Fig. 4 Configuration of Transmitting Mechanism

Thus, the expectation and variance of the random variable function R (Resultant load) are

$$E(R) = 31.9416$$

$$V(R) = 1.7448$$

We will now consider the components of the resultant load in the X and Y axes as shown in Fig. 5.

$$\gamma_R = \cos^{-1} \frac{T_{1y} + T_{2y}}{R} = 25.005$$

Hence

X component of resultant load $R_x = R \sin\gamma_R$

Y component of resultant load $R_y = R \cos\gamma_R$

According to the properties of expectation and variance, γ_R is a constant, thus the expectation and variance of the resultant load in the x and y axes are :

$$E(R_x) = E(R)\sin\gamma_R = 13.5015$$

$$E(R_y) = E(R)\cos\gamma_R = 28.9478$$

$$V(R_x) = E(R)(\sin\gamma_R)^2 = .3117$$

$$V(R_y) = E(R)(\cos\gamma_R)^2 = 1.4331$$

The loads which act on a shaft include the tension of the belt, the weight of the sheaves and the weight distribution of the shaft. These loads are shown in Fig. 6.

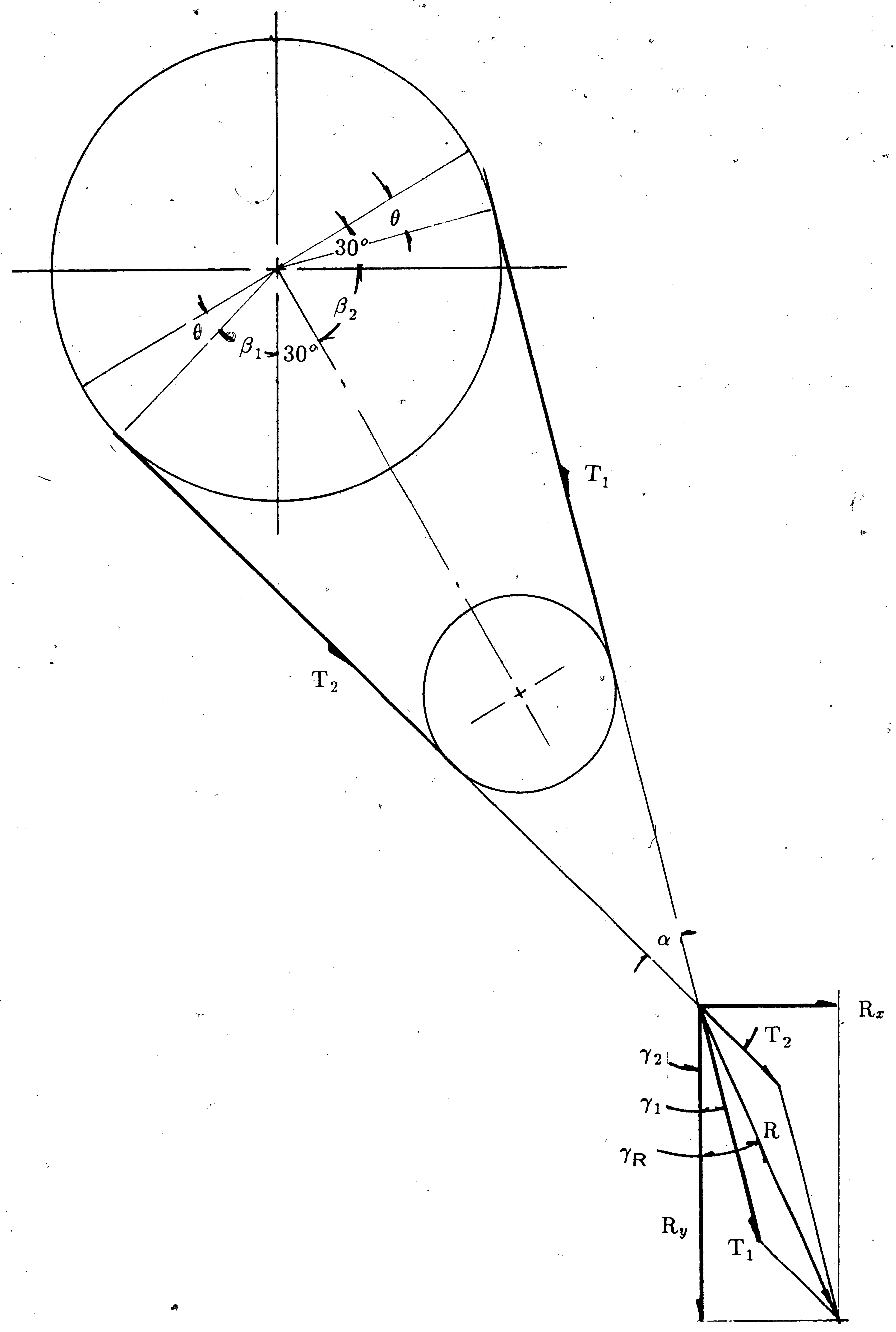
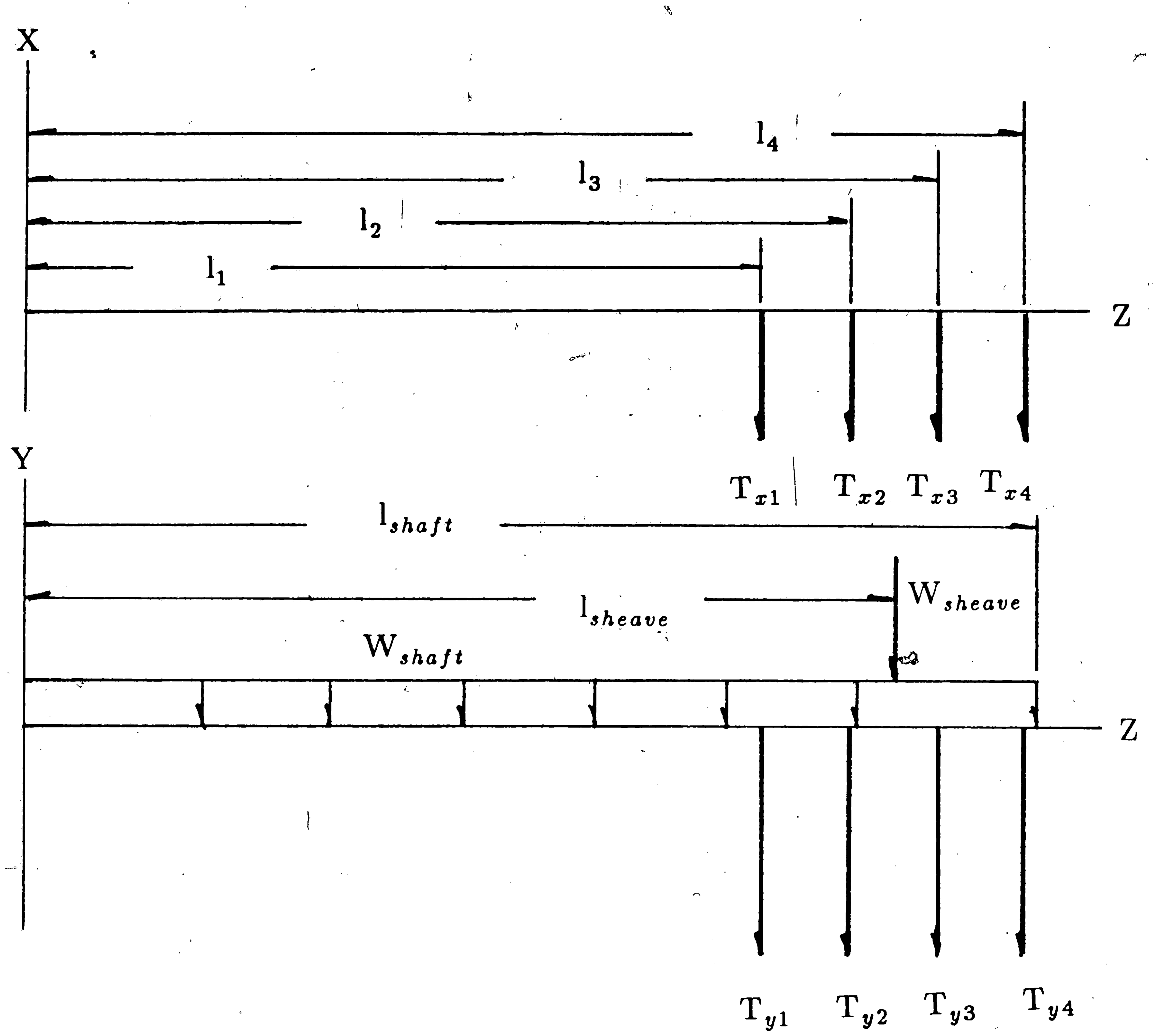


Fig. 5 Components of Resultant Load



Length of Shaft $l_{shaft} = 12$ in.

Diameter of Sheave = .75 in.	$l_4 = 12 - 1/8 - 11/32 = 11.531$ in.
Weight of Sheaves = 4.4 x 2 = 8.8 lb	$l_3 = 12 - 1/8 - 33/32 = 10.844$ in.
Distance of Sheaves = 12 - 3/2 = 10.5 in.	$l_2 = 12 - 2/8 - 55/32 = 10.031$ in.
Weight/ Foot = 1.5 lb	$l_1 = 12 - 2/8 - 77/32 = 9.344$ in.

Fig. 6 Configuration of Load Distribution

The bending moment components due to the tension of 4 belts are:

$$M_x = l_1 R_{x1} + l_2 R_{x2} + l_3 R_{x3} + l_4 R_{x4}$$

$$M_y = l_1 R_{yi} + l_2 R_{y2} + l_3 R_{y3} + l_4 R_{y4}$$

For a function of random variables, the expectation and variance are

$$E\,[\,f(x)\,] \approx f\,(\,\mu_1 \ldots\ldots\ldots\ldots\ldots\ldots \mu_n\,) \qquad (19)$$

$$V\,(\,Y\,) \approx \sum_{i=1}^{n} \{\, \frac{\partial f(x)}{\partial x_i} \Big|_{x=i} \,\}^2\, V\,(x_i) \qquad (20)$$

The expectation and variance of bending moment in x and y components are:

$$E\,(\,M_x) = E\,(\,R_x).(\,l_1 + l_2 + l_3 + l_4\,) = 563.69$$

$$E\,(\,M_y) = E\,(\,R_y).(\,l_1 + l_2 + l_3 + l_4\,) = 1208.57$$

$$V\,(\,M_x) = (\,l_1 + l_2 + l_3 + l_4\,)^2.\;V\,(\,R_x) = 543.31$$

$$V\,(\,M_y) = (\,l_1 + l_2 + l_3 + l_4\,)^2.\;V\,(\,R_y) = 2497.98$$

The bending moment due to the weight distribution of the shaft :

$$M_{shaft} = 1.5 \text{ x } 6 = 9 \text{ in-lb}$$

The bending moment due to the weight of the sheaves :

$$M_{\;sheaves} = 8.8 \text{ x } 10.5 = 92.4 \text{ in-lb}$$

The expectation and variance of bending moment in the y axis are

$$E\,(\,M_Y) = M_{sheaves} + M_{shaft} + E\,(\,M_y) = 109.16$$

$$V\,(\,M_Y) = V\,(\,M_y) = 2497.98$$

The expectation and variance of the bending moment in the x axis are

$$E\,(\,M_X) = E\,(\,M_x) = 563.69$$

$$V(M_X) = V(M_x) = 543.31$$

The actual bending moment of the shaft is the vector sum of the bending moment in the x and y axis. Here,

$$M_R = \sqrt{(M_X^2 + M_Y^2)}$$

M_X and M_Y are random variables with expectation $E(M_X)$ and $E(M_Y)$, and variance $V(M_X)$ and $V(M_Y)$. Therefore, the expectation of resultant moment can be obtained :

$$E(M_R) \approx [E(M_Y)^2 + E(M_X)^2]^{1/2} = 574.16 \text{ in-lb}$$

and the variance of the resultant moment is given by

$$V(M_R) \approx \left(\frac{\partial M_R}{\partial M_X}\right)^2 V(M_X) + \left(\frac{\partial M_R}{\partial M_Y}\right)^2 V(M_Y) = 1008.32 \text{ in-lb}$$

These equations describe the resultant bending moment which results from the tension of the belt and the weight of the components applying on the shaft.

CHAPTER 5

CONCLUSION AND FUTURE IMPLICATIONS

The bending moment of a transmitting shaft in a belt-driven mechanism results from the tension of the belt which is affected by it's length, modulus factor and the revolution speed of the belt.

In the experiment, the variation of data when a pressing force is applied on the side of an extened belt was measured. The Weibull distribution was used to determine the mean and variances of the data obtained in the tension test. Combining the load which resulted from random variable tension with the constant load which resulted from the weight of the sheaves and shaft, the statistical properties of expectation and variance of bending moment were obtained. Based on the stress due to the known bending moment and the strength of material used in the shaft, a probability computation can be executed in the shaft design.

The elasticity of the belt is a significant factor in this experiment. Different relaxations resulted in different lengths and tensions of the belt. In a standardized test where different belt were tested, optimal contact between the grooves in the sheaves and belt as well as even belt relaxation was obtained when a load of 35 pounds was applied. At this loading, the measurement of belt length and tension were the most accurate and consistant of all recorded results.

The tension tester which was used in this experiment to measure the pressing force did not yield accurate data when compared with other measured data, which were accurate when the pressing force was low. In order to improve the accuracy of force measurement, a more sensitive force gage should be used to replace the tension tester which was used in this experiment.

Finally, in order to test the tension variation of a rotating belt, a rotating belt tension test machine should be designed to measure the tensions after the belt rotates for various cycles. It may be found that tension may decrease as a function of rotations due to belt relaxation. Thus, the load which can be transmitted by a V-belt system could be predicted as a function of belt rotation.

TABLE 2
Data of Wide Range Tension Test

10 C = 5.526 L = 22.048

L(o)	q	F	L(q)	E
34.2	0.10	2.2	36.2	80979.095
33.9	0.15	2.5	38.4	16448.022
32.8	0.20	3.9	41.3	16050.909
30.8	0.25	5.1	44.8	12459.170
28.7	0.30	6.2	50.4	9612.278
25.8	0.35	8.2	61.3	9680.623
20.4	0.40	10.0	62.2	9266.290
19.0	0.42	12.0	63.8	10350.439
17.7	0.44	13.0	67.4	10058.821
15.5	0.46	14.0	68.3	9873.550
14.8	0.48	14.9	72.4	9382.115
13.9	0.50	16.5	73.5	9415.457
12.9	0.52	17.0	78.4	8721.999
12.1	0.54	18.6	82.2	8677.140
11.6	0.56	18.7	80.6	7834.768
11.3	0.58	21.0	86.2	8034.922
10.4	0.60	21.0	89.2	7302.194
10.1	0.62	24.3	90.7	7780.574
9.6	0.64	25.5	95.5	7472.663

9 C = 5.2385 L = 21.2726

L(o)	q	F	L(q)	E
34.2	0.10	2.1	34.0	57955.947
33.5	0.15	2.5	36.2	12571.699
33.0	0.20	3.3	40.2	7115.784
32.1	0.25	5.4	43.3	10909.518
30.2	0.30	7.2	49.6	10110.024
28.0	0.35	9.7	57.3	10140.562
24.7	0.40	11.0	64.4	8240.737
22.7	0.42	12.0	68.0	8233.656
20.8	0.44	17.0	77.9	11569.082
18.4	0.46	17.0	80.1	10321.647
15.5	0.48	10.5	57.5	5053.703
15.2	0.50	13.5	63.6	6186.782
15.5	0.52	15.0	71.4	6187.312
15.2	0.54	18.0	78.6	6888.993
15.3	0.56	20.2	82.6	7033.928
14.6	0.58	21.0	85.8	6644.548
14.7	0.60	23.0	88.6	6632.232

TABLE 2 (Continued)
Data of Wide Range Tension Test

8 C = 5.224 L = 21.4436

L(o)	q	F	L(q)	E
34.2	0.10	2.1	34.7	57836.649
33.4	0.15	2.7	37.6	16947.593
32.8	0.20	4.2	41.3	15439.349
31.7	0.25	5.3	44.4	10608.158
29.9	0.30	7.0	50.3	9660.809
26.7	0.35	9.8	54.8	10615.971
24.0	0.40	11.3	60.3	8714.740
21.2	0.42	12.0	62.0	8482.346
19.6	0.44	13.3	65.3	8585.844
18.5	0.46	14.6	67.2	8523.713
17.6	0.48	15.2	70.4	7914.591
16.5	0.50	16.2	73.5	7631.884
15.4	0.52	17.5	75.2	7509.229
15.2	0.54	17.5	76.5	6669.821
14.7	0.56	19.6	81.6	6851.309
13.8	0.58	21.4	84.8	6874.281
12.7	0.60	23.2	88.2	6868.883
12.3	0.62	25.0	91.6	6777.133

7 C = 5.22 L = 21.4356

L(o)	q	F	L(q)	E
34.8	0.10	1.8	36.3	34071.662
33.9	0.15	3.0	38.6	22751.739
33.0	0.20	4.0	42.7	13427.256
31.4	0.25	7.0	46.2	18654.934
29.1	0.30	7.0	51.8	9883.952
26.2	0.35	8.9	57.4	9172.682
23.3	0.40	12.0	64.0	9615.873
20.2	0.42	11.5	65.7	8129.472
19.0	0.44	13.5	68.4	8825.442
17.7	0.46	14.9	72.4	8836.398
16.4	0.48	16.9	76.4	9165.888
15.5	0.50	17.0	83.2	8195.102
14.2	0.52	19.5	80.3	8656.355
13.2	0.54	18.3	85.3	7218.800
13.0	0.56	23.0	89.8	8402.421
12.3	0.58	24.4	93.2	8107.644
11.7	0.60	24.6	98.9	7405.971

TABLE 2 (Continued)
Data of Wide Range Tension Test

6 C = 5.194 L = 21.3836

L(o)	q	F	L(q)	E
34.2	0.10	1.9	35.5	42046.962
33.7	0.15	3.0	37.6	22509.457
32.8	0.20	4.0	41.8	13286.318
31.5	0.25	5.0	46.7	9080.789
29.2	0.30	6.8	50.6	9152.283
26.4	0.35	9.0	55.9	9152.778
23.1	0.40	11.7	63.0	9173.781
20.3	0.42	12.0	64.7	8484.239
18.8	0.44	12.5	65.8	7885.142
17.8	0.46	15.0	70.1	8776.763
16.6	0.48	14.9	73.4	7714.777
15.9	0.50	17.0	76.7	8040.985
14.7	0.52	18.3	77.2	7875.530
14.1	0.54	16.0	82.3	5984.497
13.1	0.56	21.0	85.7	7462.938
13.1	0.58	22.0	88.6	7049.522
12.1	0.60	25.5	93.9	7579.703

5 C = 5.226 L = 21.4476

L(o)	q	F	L(q)	E
34.9	0.10	2.0	35.4	48644.977
33.7	0.15	2.9	37.9	20944.988
32.7	0.20	4.0	41.7	13702.416
31.0	0.25	5.5	46.1	11874.754
28.7	0.30	6.8	51.4	9504.825
26.3	0.35	9.0	56.2	9353.722
22.7	0.40	11.0	63.2	8609.107
20.1	0.42	12.0	64.0	8666.452
18.7	0.44	13.2	65.4	8639.418
17.1	0.46	13.8	69.5	8116.377
15.9	0.48	15.2	72.1	8129.704
15.6	0.50	16.4	75.9	7857.890
14.8	0.52	18.3	77.2	7995.760
14.1	0.54	19.8	81.3	7851.922
13.4	0.56	21.7	85.0	7850.052
12.7	0.58	24.2	95.4	8023.652
11.4	0.60	28.0	99.6	8604.096

TABLE 2 (Continued)
Data of Wide Range Tension Test

4 C = 5.213 L = 21.4216

L(o)	q	F	L(q)	E
34.2	0.10	1.8	35.3	35507.964
33.6	0.15	2.9	37.6	20838.102
32.8	0.20	4.0	41.6	13492.624
31.2	0.25	5.4	45.8	11212.892
29.0	0.30	6.0	49.8	7175.469
26.0	0.35	8.7	55.3	8840.824
23.0	0.40	11.0	60.1	8494.222
20.3	0.42	11.2	61.4	7788.047
19.2	0.44	11.8	63.3	7311.708
18.2	0.46	13.8	69.0	7915.908
17.0	0.48	14.0	70.1	7152.194
15.9	0.50	17.0	76.5	8121.192
15.0	0.52	17.5	75.8	7508.263
14.4	0.54	18.9	78.6	7355.778
13.4	0.56	19.2	81.9	6763.022
12.6	0.58	20.8	87.9	6712.038
12.0	0.60	21.6	89.5	6346.438

3 C = 5.2 L = 21.3956

L(o)	q	F	L(q)	E
34.4	0.10	1.5	35.3	12794.578
33.7	0.15	2.0	37.6	1194.985
33.0	0.20	4.0	41.5	13211.792
31.7	0.25	4.8	45.9	8108.425
29.4	0.30	6.0	50.4	6984.480
26.9	0.35	8.3	55.5	7891.801
24.4	0.40	10.6	62.8	7735.852
21.0	0.42	12.5	64.4	8890.004
19.3	0.44	13.8	66.2	8942.736
18.2	0.46	14.0	71.0	8009.156
17.0	0.48	14.2	74.3	7233.247
15.8	0.50	16.2	74.6	7614.443
15.2	0.52	16.7	76.4	7025.579
14.0	0.54	17.0	82.2	6472.057
13.4	0.56	17.0	83.3	5811.962
12.7	0.58	23.3	88.5	7585.951
12.1	0.60	24.0	92.9	7100.373

TABLE 2 (Continued)
Data of Wide Range Tension Test

2 C = 5.217 L = 21.4296

L(o)	q	F	L(q)	E
34.2	0.10	1.8	35.2	35649.092
33.5	0.15	3.0	37.9	23194.400
32.6	0.20	4.0	41.8	13675.715
31.3	0.25	5.3	46.5	10733.665
29.4	0.30	6.9	53.9	9502.164
27.0	0.35	9.2	59.3	9484.347
24.2	0.40	12.5	66.7	10012.708
21.1	0.42	13.0	68.4	9449.987
19.6	0.44	13.9	73.2	9067.441
18.3	0.46	16.2	75.8	9717.367
17.2	0.48	17.9	80.7	9714.293
16.1	0.50	19.2	84.1	9398.902
15.0	0.52	21.8	87.3	9753.456
14.6	0.54	24.3	88.4	9852.025
13.9	0.56	22.0	90.6	7894.742
13.2	0.58	29.0	101.3	9739.970
12.2	0.60	24.0	96.7	7153.843

1 C = 5.208 L = 21.4116

L(o)	q	F	L(q)	E
34.2	0.10	1.3	35.7	-970.151
33.5	0.15	2.0	38.8	1511.602
32.6	0.20	4.5	42.8	18113.666
31.0	0.25	4.5	47.1	7079.648
29.1	0.30	5.6	52.1	6042.690
25.9	0.35	9.0	56.3	9344.217
22.8	0.40	12.0	65.2	9638.784
19.6	0.42	11.1	65.0	7778.629
18.3	0.44	13.0	67.3	8443.485
16.7	0.46	14.5	70.7	8614.035
15.8	0.48	15.0	75.4	7934.433
14.5	0.50	17.5	78.5	8546.249
13.9	0.52	15.5	80.3	6569.373
12.9	0.54	15.8	82.2	6050.834
12.3	0.56	19.0	85.6	6760.569
11.5	0.58	20.0	93.3	6488.250
11.2	0.60	26.1	97.9	7904.469
11.3	0.62	27.0	97.2	7404.614

TABLE 3.
Data of Narrow Range Tension Test

	L(o)	q	F(a)	L(q)	E(1)
# 10	33.80	0.087	1.40	33.90	44923.159
	33.50	0.100	1.60	34.60	32964.920
C=5.5365	33.40	0.120	2.00	35.30	27019.157
L=22.0686	33.10	0.140	2.60	36.60	28535.852
C/64=.0865	32.90	0.160	2.80	38.30	18547.415
	32.30	0.180	3.10	39.70	14495.459
	32.20	0.200	3.50	41.90	12404.896
	31.70	0.220	4.00	43.70	11758.718
# 9	33.40	0.082	1.90	34.30	115296.893
	33.00	0.100	2.00	35.00	54186.132
C=5.231	32.80	0.120	2.30	35.90	33771.658
L=21.4576	32.40	0.140	2.80	37.20	28505.001
C/64=.0817	32.00	0.160	3.20	38.30	22262.597
	31.50	0.180	3.80	40.30	20540.184
	30.80	0.200	4.00	41.20	15089.898
	30.20	0.220	4.30	42.90	12129.581
# 8	34.40	0.082	1.20	34.70	16818.936
	34.10	0.100	2.00	35.30	50907.916
C=5.2265	34.00	0.120	2.50	36.30	39785.595
L=21.4486	33.70	0.140	2.80	37.50	26545.371
C/64=.08166	33.40	0.160	3.00	38.90	17076.193
	32.90	0.180	4.00	40.00	21773.410
	32.40	0.200	4.30	42.30	16664.443
	31.80	0.220	4.50	43.80	12537.745
# 7	32.10	0.082	1.00	32.20	-419.270
	31.90	0.100	2.30	32.90	78962.532
C=5.225	31.70	0.120	2.80	33.90	56918.258
L=21.4456	31.50	0.140	3.00	35.40	34991.121
C/64=.08164	31.30	0.160	3.30	36.60	24711.697
	30.80	0.180	4.50	37.80	29839.800
	30.40	0.200	4.90	39.90	23535.562
	29.90	0.220	5.20	42.10	18434.382
# 6	33.60	0.081	1.00	34.20	-6738.850
	33.20	0.100	2.30	34.50	73694.084
C=5.1945	33.00	0.120	2.90	35.80	57405.783
L=21.3846	32.70	0.140	3.30	37.20	40410.287
C/64=.08116	32.30	0.160	3.40	38.90	24832.495
	31.80	0.180	3.60	40.00	17266.613
	31.00	0.200	3.80	41.30	12738.190
	30.30	0.220	4.80	43.40	15128.809

TABLE 3 (Continued)
Data of Narrow Range Tension Test

	L(o)	q	F(a)	L(q)	E(1)
# 5	33.00	0.082	1.00	33.20	-4196.457
	32.70	0.100	1.70	33.80	32943.316
C=5.229	32.50	0.120	2.80	34.50	55515.900
L=21.4536	32.20	0.140	3.00	35.50	34090.680
C/64=.0817	31.90	0.160		36.90	
	31.40	0.180		38.50	
	30.70	0.200		39.00	
	29.90	0.220		41.00	
# 4	34.60	0.082	1.80	35.30	96752.844
	33.80	0.100	2.20	35.80	65875.094
C=5.216	33.60	0.120	2.90	36.80	57099.157
L=21.4276	33.20	0.140	3.50	37.90	45618.923
C/64=.0815	32.60	0.160	3.80	39.20	32023.682
	32.00	0.180	3.90	40.80	21134.421
	31.20	0.200	4.80	42.60	21928.560
	30.50	0.220	5.00	43.50	16610.656
# 3	33.30	0.081	1.80	33.80	102544.522
	32.90	0.100	2.40	34.50	81966.911
C=5.1985	32.60	0.120	2.60	35.30	45791.030
L=21.3926	32.30	0.140	3.00	36.30	33190.078
C/64=.0812	31.90	0.160	3.20	38.20	21812.905
	31.30	0.180	3.40	39.70	15271.513
	30.50	0.200	3.80	40.90	13126.709
	29.90	0.220	5.00	41.70	16758.310
# 2	33.70	0.081	2.10	34.30	141062.419
	33.20	0.100	2.50	34.70	88749.925
C=5.205	32.90	0.120	2.70	35.60	49627.093
L=21.4056	32.40	0.140	3.30	36.90	41133.936
C/64=.08133	31.90	0.160	3.60	38.20	29003.288
	31.20	0.180	4.10	39.60	24139.449
	30.40	0.200	4.50	40.90	19606.631
	29.50	0.220	4.70	42.80	15019.808
# 1	33.70	0.081	1.70	34.20	87147.545
	33.50	0.100	1.90	34.60	44439.801
C=5.2055	33.20	0.120	2.10	35.70	23888.489
L=21.4066	32.80	0.140	2.60	36.70	22082.857
C/64=.08134	32.30	0.160	3.00	38.00	17957.061
	31.90	0.180	3.40	39.30	14843.038
	31.40	0.200	4.00	40.40	14385.182
	30.60	0.220	4.30	42.60	11668.094

TABLE 4
Relation between Tension and Extension

#4 D	Load	dLoad/dD	#5 D	Load	dLoad/d
5.183	10		5.1855	10	
5.2045	20	465.116	5.2025	20	588.235
5.216	30	869.565	5.2195	30	588.235
5.227	40	909.090	5.2315	40	833.333
5.2365	50	1052.63	5.244	50	800
5.249	60	800	5.2535	60	1052.63
5.258	70	1111.11	5.265	70	869.565
5.2695	80	869.565	5.278	80	769.230
5.2785	90	1111.11	5.2885	90	952.380
5.289	100	952.380	5.299	100	952.380
5.3005	110	869.565	5.31	110	909.090
5.3125	120	833.333	5.3205	120	952.380
5.324	130	869.565	5.333	130	800
5.3345	140	952.380	5.346	140	769.230
5.347	150	800	5.3525	150	1538.46
5.361	160	714.285	5.3675	160	666.666
5.37	170	1111.11	5.3775	170	1000
5.3835	180	740.740	5.3915	180	714.285
85.401	190	0.12497	5.3985	190	1428.57

#6 D	Load	dLoad/dD	#7 D	Load	dLoad/dD
5.155	10		5.1735	10	
5.1775	20	444.444	5.195	20	465.116
5.1945	30	588.235	5.22	30	400
5.2105	40	625	5.23	40	1000
5.215	50	2222.22	5.2365	50	1538.46
5.2235	60	1176.47	5.247	60	952.380
5.2375	70	714.285	5.258	70	909.090
5.247	80	1052.63	5.268	80	1000
5.258	90	909.090	5.279	90	909.090
5.267	100	1111.11	5.2895	100	952.380
5.2805	110	740.740	5.301	110	869.565
5.2895	120	1111.11	5.3095	120	1176.47
5.3005	130	909.090	5.32	130	952.380
5.3085	140	1250	5.331	140	909.090
5.3225	150	714.285	5.343	150	833.333
5.333	160	952.380	5.355	160	833.333
5.3435	170	952.380	5.3635	170	1176.47
5.3575	180	714.285	5.3745	180	909.090
5.3665	190	1111.11	5.3875	190	769.230

TABLE 5
Data of Belt Relaxation Test

#4	70 lb	#5	70 lb	#6	70lb	#7	70lb
Time	Load	Time	Load	Time	Load	Time	Load
0'05	69	0'05	69.4	0'05	69	0'05	68.6
10	68.5	10	69.1	10	68.4	10	68.2
15	68.2	15	68.8	15	68.1	15	67.8
20	67.9	20	68.5	20	67.9	20	67.6
25	67.8	30	68.3	25	67.7	25	67.4
30	67.6	40	68.1	30	67.6	30	67.3
40	67.3	50	67.9	40	67.3	40	67
50	67.2	1'05	67.7	50	67.1	50	66.8
1'00	67	10	67.6	1'00	67	1'00	66.7
10	66.9	20	67.5	10	66.9	10	66.6
20	66.8	30	67.4	20	66.8	20	66.4
30	66.7	40	67.4	30	66.7	30	66.4
40	66.6	50	67.3	40	66.6	40	66.3
50	66.5	2'05	67.2	50	66.5	50	66.2
2'00	66.4	10		2'00	66.4	2'00	66.1
10	66.4	20	67.1	17	66.3	13	66
20	66.3	30		31	66.2	31	65.9
30	66.2	40	67	56	66.1	50	65.8
40	66.2	50		3'16	66	3'10	65.7
50	66.1	3'00	66.9	38	65.9	36	65.6
3'00	66.1	18	66.8	4'13	65.8	4'01	65.5
10	66	49	66.7			30	65.4
20	66	4'22	66.6			5'06	65.3
30	65.9	55	66.5			39	65.2
40	65.9	5'40	66.4			6'25	65.1
50	65.9					7'12	65
4'00	65.8						
20	65.7						
58	65.6						
5'35	65.5						

TABLE 6

Data of Lateral Force Effect Test

1st		2nd		3rd	
Force (lb)	Load (lb)	Force (lb)	Load (lb)	Force (lb)	Load (lb)
10	-.4	10	-.4	10	-.4
15	-.5	15	-.5	15	-.5
20	-.8	20	-.7	20	-.8
25	-1.0	25	-1.1	25	-1.1
30	-1.5	30	-1.6	30	-1.5

4th		5th		6th	
Force (lb)	Load (lb)	Force (lb)	Load (lb)	Force (lb)	Load (lb)
10	-.4	10	-.4	10	-.4
15	-.5	15	-.5	15	-.5
20	-.8	20	-.8	20	-.8
25	-1.0	25	-1.1	25	-1.1
30	-1.5	30	-1.6	30	-1.5

TABLE 7
Belt Cross Section Modulus

	q	T(q)	F(b)	E(2)
# 10	0.087	16.95	1.06	340.801
	0.100	17.30	1.25	3291.192
C=5.5365	0.120	17.65	1.53	3960.121
L=22.0686	0.140	18.30	1.85	5381.815
C/64=.0865	0.160	19.15	2.21	6367.116
	0.180	19.85	2.58	6897.634
	0.200	20.95	3.02	7324.168
	0.220	21.85	3.46	7486.645
# 9	0.082	17.15	1.07	3713.294
	0.100	17.50	1.34	5540.529
C=5.231	0.120	17.95	1.65	5967.433
L=21.4576	0.140	18.60	1.99	6795.991
C/64=.0817	0.160	19.15	2.34	6827.346
	0.180	20.15	2.77	7539.191
	0.200	20.60	3.14	7211.773
	0.220	21.45	3.60	7275.636
# 8	0.082	17.35	1.08	1189.669
	0.100	17.65	1.35	3290.680
C=5.2265	0.120	18.15	1.67	4401.893
L=21.4486	0.140	18.75	2.01	5356.691
C/64=.08166	0.160	19.45	2.38	5941.460
	0.180	20.00	2.75	6059.556
	0.200	21.15	3.23	6849.840
	0.220	21.90	3.67	6859.017
# 7	0.082	16.10	1.01	354.266
	0.100	16.45	1.26	2733.888
C=5.225	0.120	16.95	1.56	4210.352
L=21.4456	0.140	17.70	1.89	5501.586
C/64=.08164	0.160	18.30	2.24	5724.731
	0.180	18.90	2.60	5974.961
	0.200	19.95	3.05	6571.637
	0.220	21.05	3.53	6975.266
# 6	0.081	17.10	1.07	2459.256
	0.100	17.25	1.33	3539.239
C=5.1945	0.120	17.90	1.65	5326.262
L=21.3846	0.140	18.60	2.00	6299.492
C/64=.08116	0.160	19.45	2.39	7079.758
	0.180	20.00	2.77	6946.316
	0.200	20.65	3.17	7066.288
	0.220	21.70	3.66	7427.560

TABLE 7 (Continued)
Belt Cross Section Modulus

	q	T(q)	F(b)	E(2)
# 5	0.082	16.60	1.04	772.263
	0.100	16.90	1.29	3015.713
C=5.229	0.120	17.25	1.58	3824.507
L=21.4536	0.140	17.75	1.90	4649.230
C/64=.0817	0.160	18.45	2.25	5402.097
	0.180	19.25	2.64	6067.012
	0.200	19.50	2.97	5739.727
	0.220	20.50	3.44	6348.194
# 4	0.082	17.65	1.10	2872.198
	0.100	17.90	1.37	5514.865
C=5.216	0.120	18.40	1.69	6133.774
L=21.4276	0.140	18.95	2.03	6622.600
C/64=.0815	0.160	19.60	2.40	7123.400
	0.180	20.40	2.81	7505.568
	0.200	21.30	3.26	7876.236
	0.220	21.75	3.66	7416.097
# 3	0.081	16.90	1.06	2038.840
	0.100	17.25	1.33	4377.470
C=5.1985	0.120	17.65	1.63	5140.426
L=21.3926	0.140	18.15	1.95	5599.423
C/64=.0812	0.160	19.10	2.35	6763.610
	0.180	19.85	2.74	7126.626
	0.200	20.45	3.14	7144.830
	0.220	20.85	3.52	6692.918
# 2	0.081	17.15	1.07	2456.13
	0.100	17.35	1.33	4106.83
C=5.205	0.120	17.80	1.64	5149.55
L=21.4056	0.140	18.45	1.98	6319.35
C/64=.08133	0.160	19.10	2.34	6776.38
	0.180	19.80	2.73	7140.28
	0.200	20.45	3.13	7227.95
	0.220	21.40	3.61	7566.57
# 1	0.081	17.10	1.07	2035.021
	0.100	17.30	1.33	2993.317
C=5.2055	0.120	17.85	1.64	4763.173
L=21.4066	0.140	18.35	1.97	5467.879
C/64=.08134	0.160	19.00	2.33	6124.848
	0.180	19.65	2.71	6282.115
	0.200	20.20	3.10	6185.351
	0.220	21.30	3.59	6819.820

TABLE 8
Tension of Belt

	E(2)	F(b)	q	Ts
# 10	340.801	1.06	0.087	16.90
	3291.192	1.25	0.100	16.75
C=5.5365	3960.121	1.53	0.120	16.70
L=22.0686	5381.815	1.85	0.140	16.55
C/64=.0865	6367.116	2.21	0.160	16.45
	6897.634	2.58	0.180	16.15
	7324.168	3.02	0.200	16.10
	7486.645	3.46	0.220	15.85
# 9	3713.294	1.07	0.082	16.70
	5540.529	1.34	0.100	16.50
C=5.231	5967.433	1.65	0.120	16.40
L=21.4576	6795.991	1.99	0.140	16.20
C/64=.0817	6827.346	2.34	0.160	16.00
	7539.191	2.77	0.180	15.75
	7211.773	3.14	0.200	15.40
	7275.636	3.60	0.220	15.10
# 8	1189.669	1.08	0.082	17.20
	3290.680	1.35	0.100	17.05
C=5.2265	4401.893	1.67	0.120	17.00
L=21.4486	5356.691	2.01	0.140	16.85
C/64=.08166	5941.460	2.38	0.160	16.70
	6059.556	2.75	0.180	16.45
	6849.840	3.23	0.200	16.20
	6859.017	3.67	0.220	15.90
# 7	354.266	1.01	0.082	16.05
	2733.888	1.26	0.100	15.95
C=5.225	4210.352	1.56	0.120	15.85
L=21.4456	5501.586	1.89	0.140	15.75
C/64=.08164	5724.731	2.24	0.160	15.65
	5974.961	2.60	0.180	15.40
	6571.637	3.05	0.200	15.20
	6975.266	3.53	0.220	14.95
# 6	2459.256	1.07	0.081	16.80
	3539.239	1.33	0.100	16.60
C=5.1945	5326.262	1.65	0.120	16.50
L=21.3846	6299.492	2.00	0.140	16.35
C/64=.08116	7079.758	2.39	0.160	16.15
	6946.316	2.77	0.180	15.90
	7066.288	3.17	0.200	15.50
	7427.560	3.66	0.220	15.15

TABLE 8 (Continued)
Tension of Belt

	E(2)	F(b)	q	Ts
# 5	772.263	1.04	0.082	16.50
	3015.713	1.29	0.100	16.35
C=5.229	3824.507	1.58	0.120	16.25
L=21.4536	4649.230	1.90	0.140	16.10
C/64=.0817	5402.097	2.25	0.160	15.95
	6067.012	2.64	0.180	15.70
	5739.727	2.97	0.200	15.35
	6348.194	3.44	0.220	14.95
# 4	2872.198	1.10	0.082	17.30
	5514.865	1.37	0.100	16.90
C=5.216	6133.774	1.69	0.120	16.80
L=21.4276	6622.600	2.03	0.140	16.60
C/64=.0815	7123.400	2.40	0.160	16.30
	7505.568	2.81	0.180	16.00
	7876.236	3.26	0.200	15.60
	7416.097	3.66	0.220	15.25
# 3	2038.840	1.06	0.081	16.65
	4377.470	1.33	0.100	16.45
C=5.1985	5140.426	1.63	0.120	16.30
L=21.3926	5599.423	1.95	0.140	16.15
C/64=.0812	6763.610	2.35	0.160	15.95
	7126.626	2.74	0.180	15.65
	7144.830	3.14	0.200	15.25
	6692.918	3.52	0.220	14.95
# 2	2456.13	1.07	0.081	16.85
	4106.83	1.33	0.100	16.60
C=5.205	5149.55	1.64	0.120	16.45
L=21.4056	6319.35	1.98	0.140	16.20
C/64=.08133	6776.38	2.34	0.160	15.95
	7140.28	2.73	0.180	15.60
	7227.95	3.13	0.200	15.20
	7566.57	3.61	0.220	14.75
# 1	2035.021	1.07	0.081	16.85
	2993.317	1.33	0.100	16.75
C=5.2055	4763.173	1.64	0.120	16.60
L=21.4066	5467.879	1.97	0.140	16.40
C/64=.08134	6124.848	2.33	0.160	16.15
	6282.115	2.71	0.180	15.95
	6185.351	3.10	0.200	15.70
	6819.820	3.59	0.220	15.30

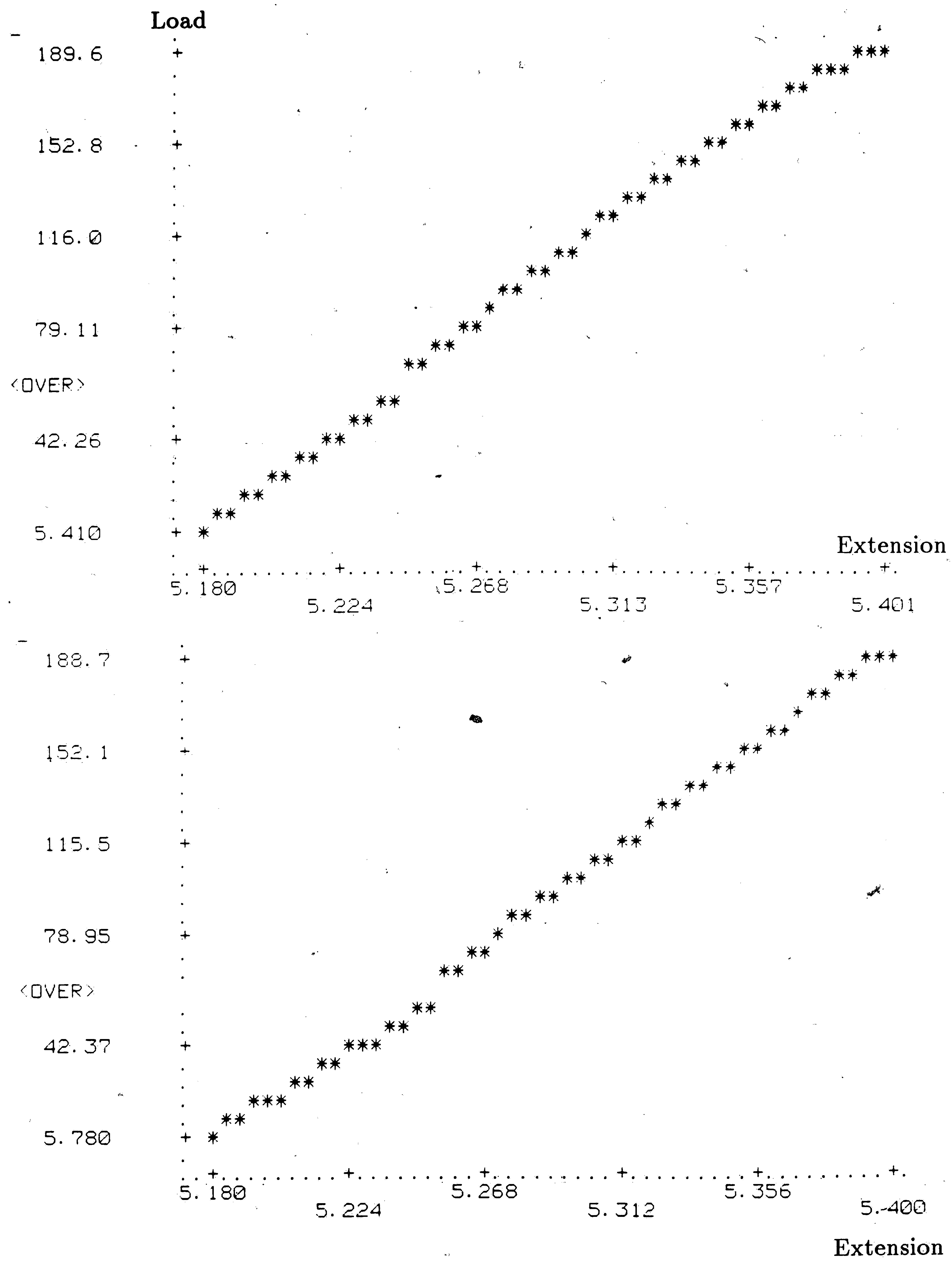
TABLE 9

Median Rank and Natural Logarithm

Belt # 10		Belt # 9		Belt #8		Median Rank	$\ln[\ln\frac{1}{1-F(T_s)}]$
Tension	$Ln(T_s)$	Tension	$Ln(T_s)$	Tension	$Ln(T_s)$	$F(T_s)$	(n=24)
16.90	2.8273	16.7	2.8154	17.20	2.8449	.02847	-3.54
16.75	2.8184	16.50	2.8034	17.05	2.8362	.06895	-2.64
16.70	2.8154	16.40	2.7973	17.00	2.8332	.10987	-2.15
16.55	2.8064	16.20	2.7850	16.85	2.8244	.15088	-1.81
16.45	2.8003	16.00	2.7726	16.70	2.8154	.19192	-1.55
16.15	2.7819	15.75	2.7568	16.45	2.8003	.23299	-1.33
16.10	2.7788	15.40	2.7344	16.20	2.7850	.27406	-1.14
15.85	2.7632	15.10	2.7147	15.90	2.7663	.31513	-0.97
						.35621	-0.82
						.39729	-0.68
						.43837	-0.55
						.47946	-0.43
						.52054	-0.31
						.56162	-0.19
						.60271	-0.08
						.64379	0.03
						.68487	0.14
						.72594	0.26
						.76701	0.38
						.80808	0.50
						.84912	0.64
						.89013	0.79
						.93105	0.98
						.97153	1.27

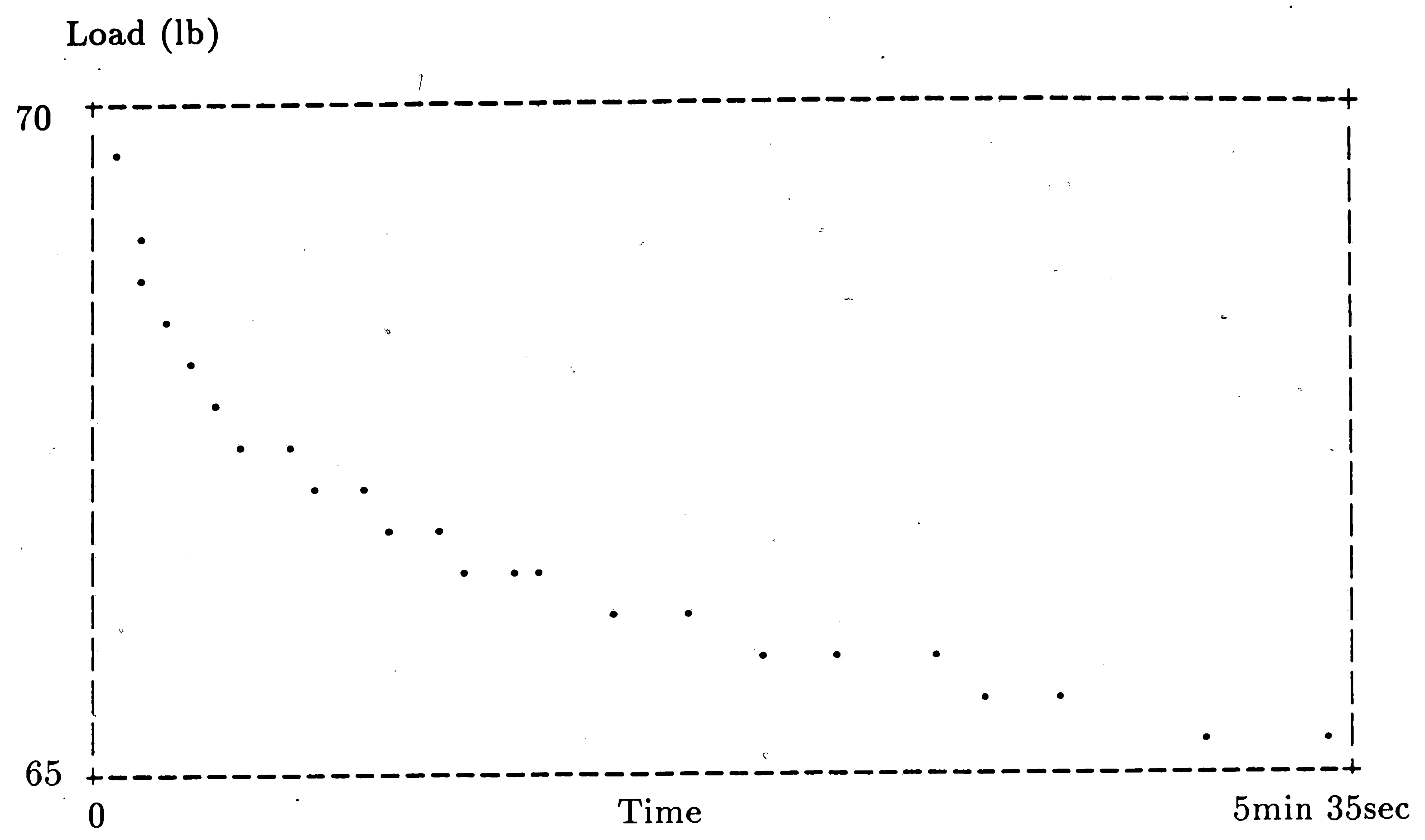
GRAPH 1.

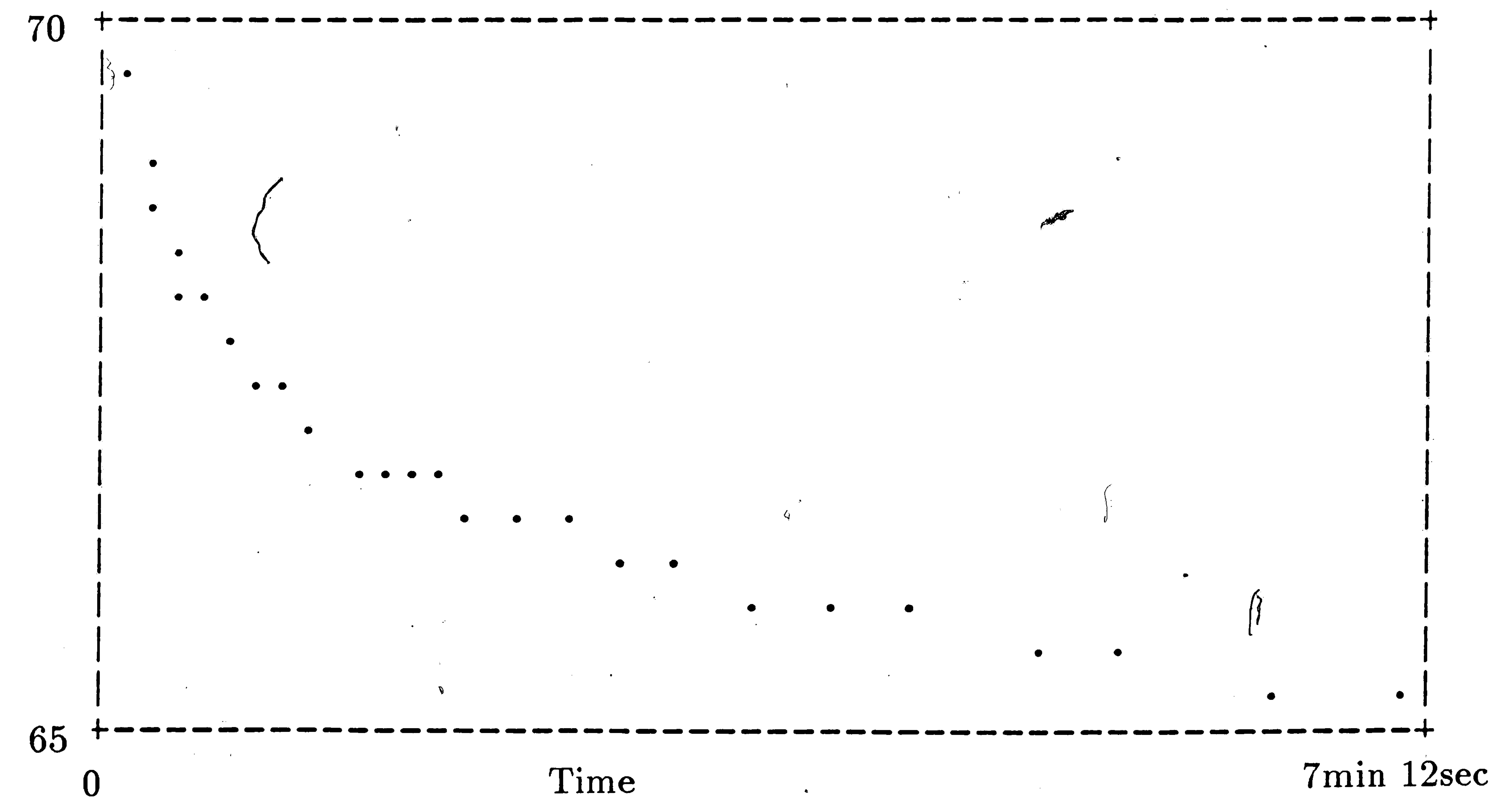
The Relation Between Tension and Extension of Belt



GRAPH 2.

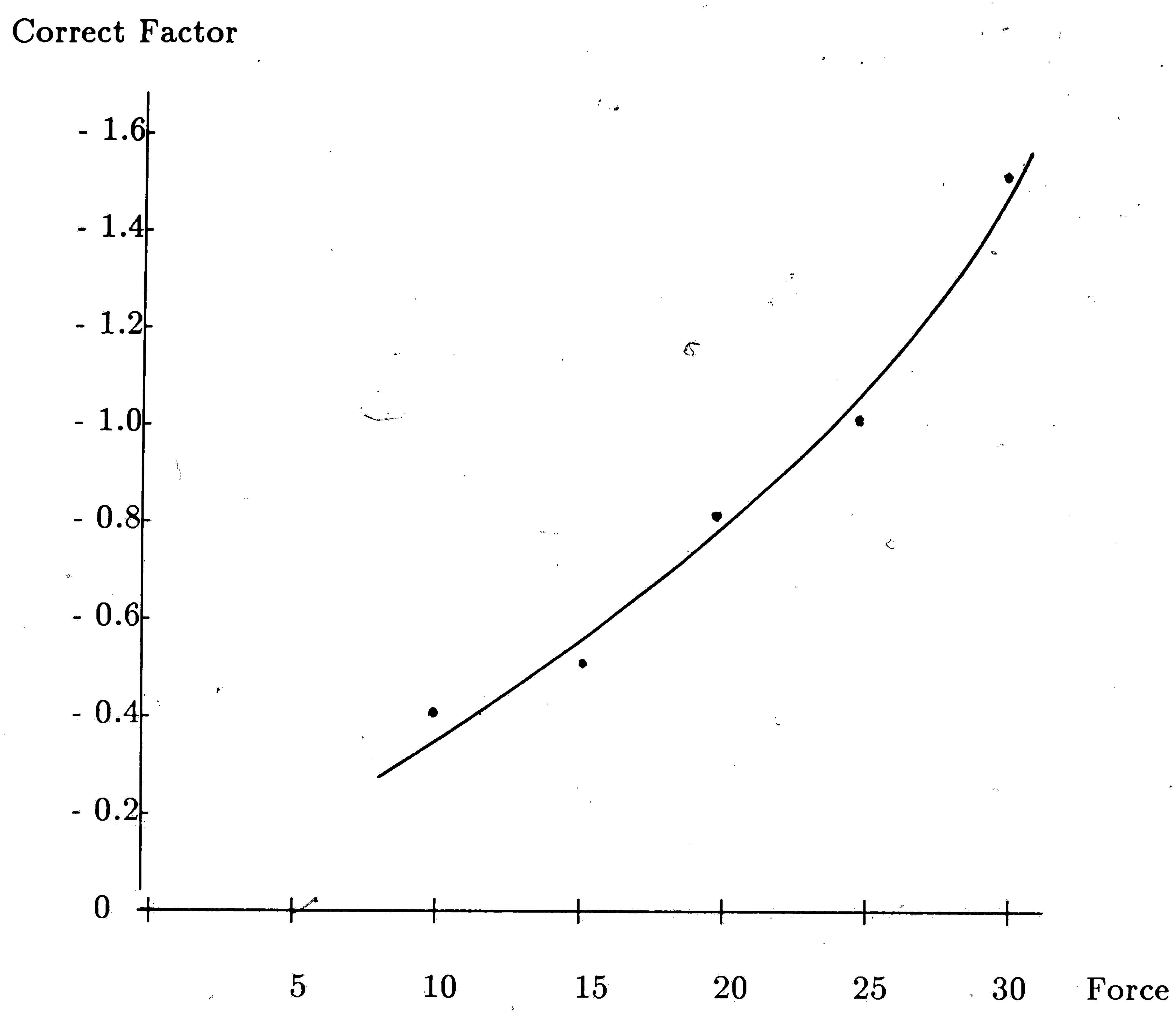
The Relaxation of An Extended Belt





GRAPH 3.

Correction Factor for Laterial Force



Press Force : 1.0 ~ 3.6 lb.

Correct to INSTRON Readout : -.04 ~ -.1 lb.

Correct to Tension : -.02 ~ -.05 lb

$T_s \approx 16$ lb $\gg .05$

Therefore, lateral force effect can be neglected.

APPENDIX 1.

Specification of INSTRON

Type : Universal Testing Instrument

Model : 1000

Function : Tension and Compression

Load Transducer Types : English : 1000 lb, 100 lb, 10 lb.

Metric : 500 kg, 50 kg, 5 kg.

Crosshead Speed :

Dial	1	2	3	4	5	6	7
in/min	0.5	1.0	2.0	5.0	10.0	12.0	20.0
mm/min	10	20	50	100	200	300	500

Table of Decimal Point Settings for the Load Ranges

Transducer Type	Range Switch	Full Scale Load	Decimal Point Setting
1000 lb	1	100 lb	100.0
	2	200	199.9
	5	500	500
	10	1000	1000
100 lb	1	10 lb	10.00
	2	20	19.99
	5	50	50.0
	10	100	100.0
10 lb	1	1 lb	1.000
	2	2	1.999
	5	5	5.00
	10	10	10.00

APPENDIX 2.

Specification of V-belt

Type : Fractional HP Sealed-life II V-belts

(used for light duty fractional HP single belt drivrs)

Model : 4L

Part No. : 108838 (4L215)

Dimension : Width 1/2 in. Thickness 5/16 in. Length 21.5 in.

Weight .11 lb.

APPENDIX 3.

Specification of FHP Sheave

Type : Light duty fractional HP one groove bored-to-size sheave.

Model : Solid with hub, 4L, no keyway.

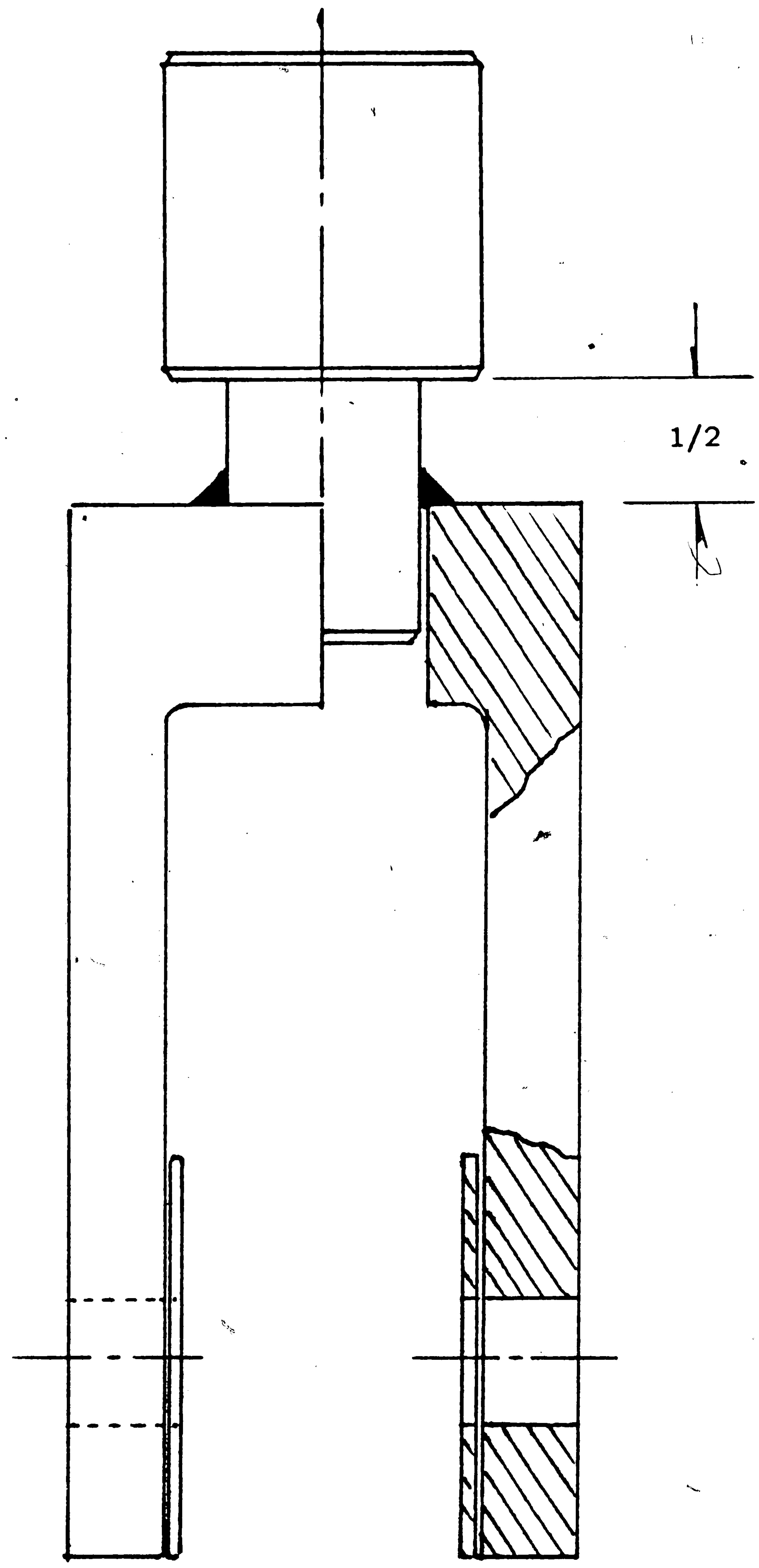
Part No. : 121676 (1A35)

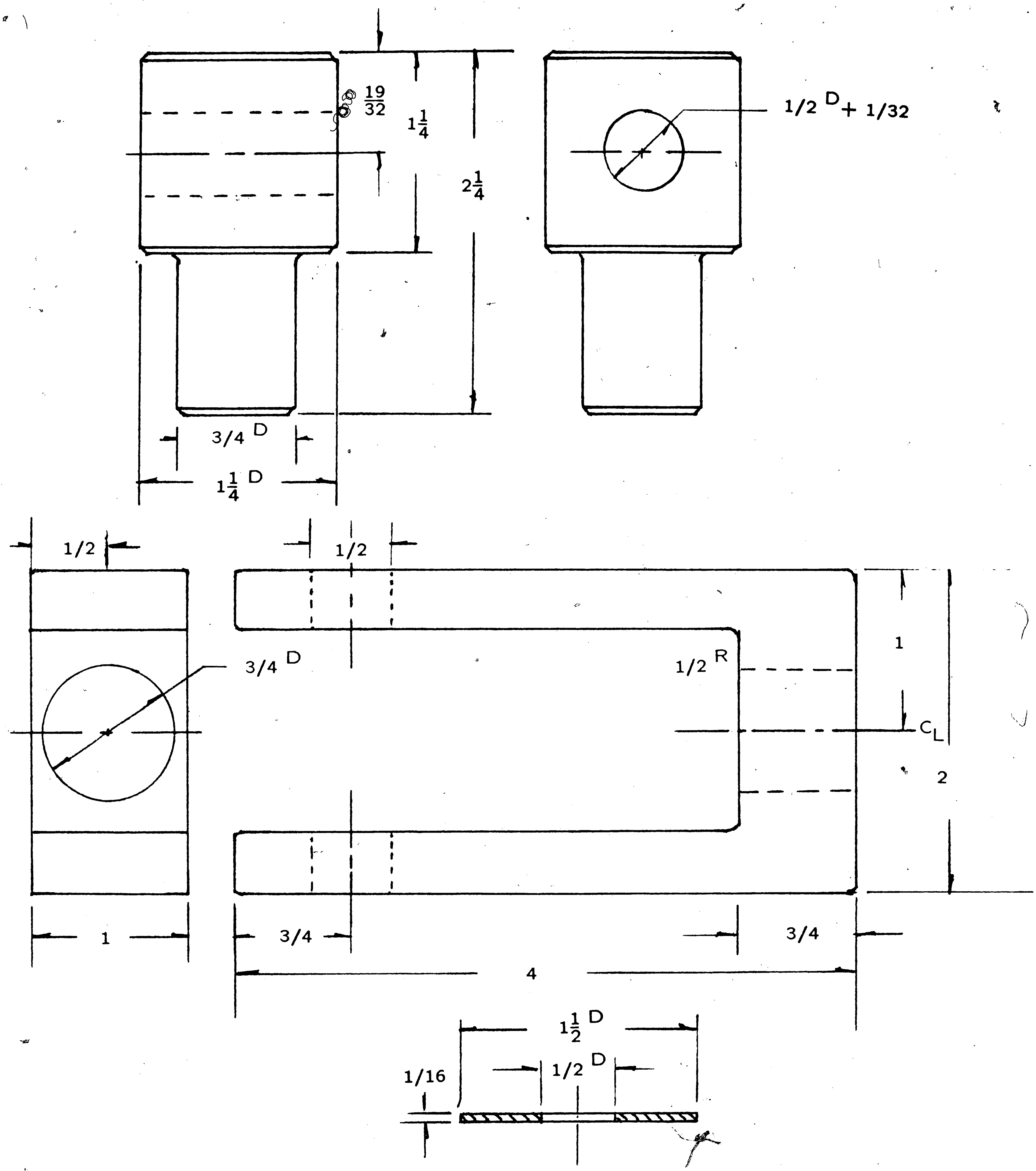
Dimension : Bore Size 1/2 in. O.D. 3.5 in. P.D. 3.2 Avg. Wt. 1.2 lb.

$F = 3/4$ in. $L = 1\frac{1}{16}$ in. $M = \frac{7}{16}$ in.

APPENDIX 4.

Fixture Design




19/32
1 1/4
2 1/4
1/2 D + 1/32
3/4 D
1 1/4 D
1/2
1/2
3/4 D
1/2 R
1
CL
2
1
3/4
3/4
4
1 1/2 D
1/16
1/2 D

APPENDIX 5.

Calculation on Weld Strength

Estimate the Strength of Fillet Weld (Ref.: Fundamentals of Machine Component Design p.338, by Robert C. Juvinall)

A. Calculation of O.D.=3.5 in.

Throat Area = txL   Throat Length t =.707xh

Assume :

$$h = .2 \text{ in.} \qquad L = \pi x D = .75 \text{ x } \pi = 2.36 \text{ in.}$$

Throad Area = txh = .707 x .2 x 2.36 = .33 in.^{2}

Yield Strength of AISI 1020 Steel : $S_Y = 50$ ksi

Using the Distortion-Energy Theory $S_{SY} = .58\ S_Y = 29$ ksi

Assume the Safety Factor is 3

$$F = \frac{S_{SY}\ A}{S.F.} = \frac{29 \text{ x } .33}{3} = 3.19 \text{ klb} = 3190 \text{ lb.}$$

The strength of fillet weld (3190 lb) is much larger than the operation load (300 lb), thus the weld design is reliable.

APPENDIX 6.

Procedure of INSTRON Calibration

1. Set readout mode : Track.

2. Set range switch : 1/5.

3. Insert the retaining pin. (this step can be neglected in 1000 lb transducer used)

4. Zeroing :

   * Holding the zero/cal switch.

   * Unlock coarse & fine balance controls. (counterclockwise 1/4 cycle)

   * Adjust controls : load readout shows zero.

   * Lock the control.

5. Balancing :

   * Release the zero/cal switch.

   * Set the range switch at 10/50.

   * The load read from the readout should be less than 5% of full scale of load range.

   * If the load reading is greater than 50 lb, use screwdriver to adjust the LVDT core extender shaft in the crosshead untill a null. (a minimum reading occurs.)

   * Rotate the adjustment clockwise and counterclockwise to locate the null.

6. Calibrating : (for 1000 lb transducer)

   * Set range switch to 10/50 position.

   * Set zero/cal switch on the CAL position.

   * Turn the ADJ trimmer until the load readout matches the proper calibration number stamped on the load transducer.

APPENDIX 6. (Continued)

Procedure of INSTRON Calibration

7. Recheck the calibration after the upper grip is installed.

    * Repeat step 1, 2, 4, and 6 of the calibration procedure.

    * After check calibration, the load readout will show tare weight of grip.

    * Adjust balance controls to set the load readout to be zero.

APPENDIX 7.

Related Data of EXPLORE

All the data shown in Table 9. Median Rank and Nature Logarithm.

Variable	X : $\ln(T_s)$	Y : $\ln[\ln \frac{1}{1-F(T_s)}]$
Mean	2.794875	-.55
St. Dev.	3.241202E-02	1.186921

ANOVA TABLE

Source of Variation	Sum of Squares	D.F.	Mean Square
Regression	32.1959	1	32.1959
Error	.2061013	22	9.368242E-03
Total	32.402	23	

F for analysis of variance = 3436.71
D.F. = 1 and 22 (for F-test)
R-Squared = 0.9936
Per cent of variation explained = 99.36
Multiple correlation coefficient = 0.9968
Standard error of estimate = 9.678967E-02

TABLE OF ESTIMATED COEFFICIENTS

Variable	Estimated Coefficient	Estimated St. Dev.	Computed t-Value
X	36.503143	0.622671	58.623
Intercept	-102.5717		

GENERAL SUMMARY

Number of Observations = 24

Mean of X = 2.794875

Mean of Y = -.55

Correlation Coefficient = .9968
For X : each space = 2.603998E-03 units

For Y : each space = .3206667 units

X goes from 2.7147 to 2.8449

Y goes from -3.54 to 1.27

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BIOGRAPHY

Cheng-Chien Shen was born in Tainan, Taiwan, Republic of China on December 25, 1949 of Hsien-Jen and Chao-Nan Shen. He obtained a Bachelor of Science Degree in Aeronautical Engineering from Chung Cheng Institute of Technology in 1973.

His professional experience included three years service in the Air Force as an Aircraft Structure Engineer and twelve years service in the Ordnance Production Service as a design and manufacturing engineer.